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Influence of the Treatment Method on the Water Yielding Capacity of Natural Water Sediments

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Abstract

Low water yielding capacity of natural water sediments complicates the treatment and recycling processes. It is caused by their peculiar structure and hydroxide composition distinct from other kinds of sediments. Elemental composition of the sediments of treatment facilities has been studied with the use of a scanning electron microscope, the grain-size composition has been determined using light scattering of water suspensions. In order to intensify the sludge dehydration of the water-supply network treatment facilities, the following methods has been investigated: the temperature treatment (freezing with subsequent thawing), the flocculant treatment, and the joint treatment with a flocculant and a filler (vermiculite). The properties and the structures of natural and conditioned sediments have been studied, which allows choosing the optimal treatment method. It has been shown that the use of the polyacrylamide-based flocculant together with vermiculite is a promising technique to increase the water yielding capacity of sediments along with freezing. Optimal amounts of the flocculant and vermiculite have been suggested.

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Keywords: natural water sediments; water yielding capacity; flocculant; vermiculite.

Drinking-water treatment technique involves formation of abundant sediments that have peculiar structure and properties, distinct from other kinds of sediments. Until very recently, the treatment of the sediments formed after purification of natural waters did not get sufficient attention, and at present there are but a few papers in public media that discuss the problems of the treatment and recycling of such sediments. In view of this, nowadays the uniform methods for solution of such a problem are absent, therefore the water-supply network treatment facilities have no science-based way to decide an issue of recycling such sediments. The difficulties are largely owing to the

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fact that the composition and properties of natural water sediments are determined by the quality of water in the source, which is very diverse in composition and subject to significant seasonal fluctuations [1].

The object of our studies is the sediments of the water-supply network treatment facilities of Chelyabinsk city, the water source of which is the Shershnyovskoye reservoir on the Miass river. In chemical composition its water is of the hydrocarbonate class, the calcium group; its turbidity is low (1.5...40 mg/L), the water colour index can be medium and high, depending on the season (18...200 degrees). The cause of the water colour is the presence of humic compounds – humic and fulvic acids and their salts [2-6].

The operational flow scheme of water treatment in the treatment facilities includes the reactant purification with the use of coagulants, such as aluminum sulfate $Al_2(SO_4)_3$ or highly basic aluminum oxychloride $Al(OH)_5Cl$ and the anionic flocculant in doses not less than 4.5 mg/L. Permanganate addition is used for efficient lowering the water colour index. The conditions of sediment formation determine its hydroxide basis, high water production and high specific filtration resistance. The most important process for the sediment formation is the interaction between the negatively charged particles of impurities in water and the positively charged particles formed during coagulant hydrolysis. Consequently, during the sediment formation the following processes take place: coagulation of impurities, sorption of organic colloids on free adsorption centers of aluminum hydroxide; coprecipitation of impurities because of their mechanical inclusion in settling flocks. Precipitating, this sludge combines into the uniform gel-like three-dimensional structure, containing significant amount of water, with the help of OH bonds, due to aggregation through the polymer chains of flocculants [7, 8]. Water in the sediment exists in both bound and free state. The bound water is confined within because of physicochemical interaction (adsorption forces, capillary condensation), as well as chemical bonds (water of the hydration shell, OH groups). Free water is mechanically included in the porous structure of the sediment.

The aim of the present study is to provide recommendations for conditioning the natural water sediments, on the basis of investigation of their composition and properties.

We have studied the sediments of double-deck settling basins, sampled at purging in autumn (September – October). The averaged water quality indicators in the reservoir during this period are characterized by the following values: plankton content 20...30 mln. cell/L, water colour index (C) 14 degrees, turbidity (T) 2.9 mg/L. According to the ratio C / T the sediment can be characterized as medium in turbidity and colour [9, 10]. In appearance the sediment is a gel-like aggregation, moisture content is 97.8%, the solid phase concentration is 22 g/L.

In order to study the solid phase composition we have used a scanning electron microscope JSM-700 1F. The elemental composition has been determined in a sample, dried under vacuum at 70° C until constant weight is obtained. The results are shown in Table 1.

Table 1. Elemental composition of the sediment.

Element	C	O	Al	Si	Fe	Ca	Mn	S, P	Mg	K, Na
Natural sediment, % m/m	34.22	53.75	5.91	2.54	1.57	1.06	0.40	0.25	0.12	0.19

The presence of carbon in the sediments results from the significant amount of phytoplankton in the water source. Essential part of silicon is caused by the presence of diatom, containing this element in the cell membranes, in the phytoplankton. The presence of aluminum is explained by the use of aluminum-based salts as the coagulant, while the presence of manganese is due to permanganate addition in the summer period.

Besides, the obtained samples have been studied as to their grain-size composition in the range 0.5 ... 1000 μm by light scattering of water suspensions formed under ultrasonic exposure for 60 s at 25 W, on a MICROTRAC S 3500 analyser.

The results of the grain-size composition investigation of the natural sediment are shown in the figure.

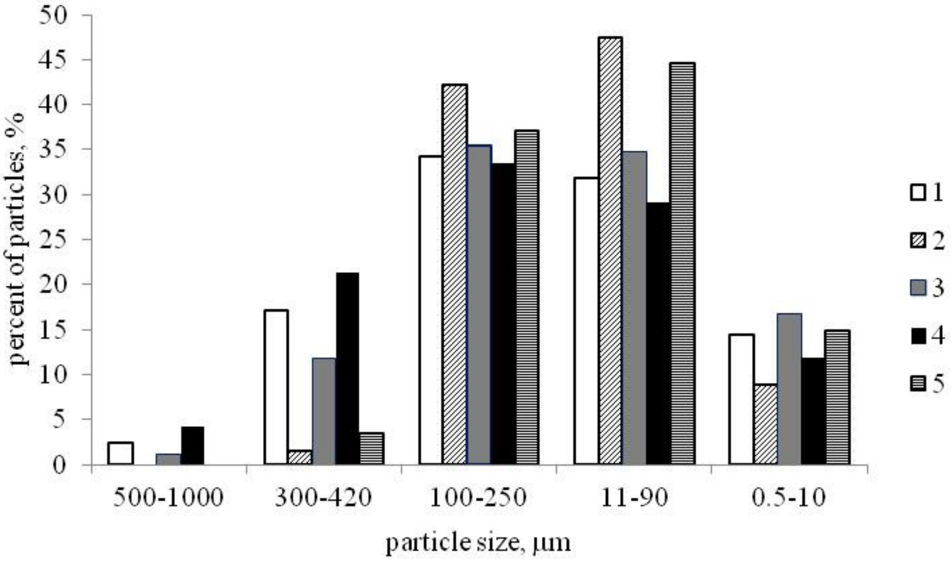

Fig. 1. Grain-size composition in the natural sediment and the sediments after conditioning. (1) natural sediment; (2) frozen sediment; (3) PAA 0.3%; (4) PAA 0.3% and vermiculite 0.6%; (5) PAA 0.3% and vermiculite 2.0%.

In paper [11] the authors suggest classification of suspensions into coarse-grained, fine-grained, slurry-like and sludge-like particles of dispersed phase, depending on the size of predominant suspended particles. The boundary between suspensions and colloids is within the frame of 0.1 ... 1 μm. On the basis of this classification, Table 2 shows the grain-size composition of the investigated sediment.

Table 2. Grain-size composition of the natural sediment

	Particle size, μm			
	Coarse-grained suspensions more than 300	Fine-grained suspensions 250…100	Slurry-like particles 90…11	Sludge-like particles 10…0.8
% m/m	20.0	34.0	32.0	14.0

As can be seen from Table 2 and the figure, the natural water sediments fall into category of suspensions, they are polydisperse with the particle sizes from 0.5 to 1000 μm. The extended surface of suspensions, the presence of electrochemical potential on the particle interface, and their hydration significantly influence the stability and water yielding capacity of such structures.

In order to determine the specific filtration resistance of the sediment we have chosen the volumetric method suggested by Coakley and Johnson [12, 13]; it consists of filtration under vacuum (500 torr) of a certain volume of the sediment. According to the investigation results, the value of specific filtration resistance of the initial sediment amounts to $6300 \cdot 10^{10}$ m/kg, that is, the sediment is difficult to filter, therefore its dehydration necessitates previous conditioning.

The cause of low water yielding capacity of the natural water sediments is the fact that the sediments obtained in the course of coagulation and flocculation can form continuous grid structures, in which separate flocks are connected to each other in all or essential volume. Structurization of such disperse systems, namely, sol-gel transformation, "stiffening" of a sedimentary unstable suspension into a uniform nonsegregating system takes place at direct contact of particles in the dispersed phase (lyophobic coagulation) or as the result of cohesion through residual layers of the dispersion phase (lyophilic coagulation) [11]. In the case of lyophilic coagulation, a loose coagulated structure is formed, which contains a large amount of immobilized water in the form of intermicelle liquid. Such coagulation structures slow down the caking process and interfere with dehydration. Weakening of coagulation structures helps in getting thicker sediments at caking, lower down the cake moisture at dehydration.

On the basis of the literature data [12, 14–17] the following methods of sediment conditioning have been chosen: freezing with subsequent thawing; flocculant treatment; using a filler together with flocculant treatment.

As a flocculant, Besfloc series 6841 has been chosen; it is a cationic polymer on the basis of polyacrylamide (PAA). The flocculant was introduced at slow stirring in the doses 0.2, 0.3, and 0.5% m/m, in conversion to dry solids of the precipitate; if only the flocculant was used, the specific filtration resistance of the obtained sediments amounted to 2370×10^{10}, 1861×10^{10}, and 647×10^{10} m/kg, the cake moisture equalled 97.0, 95.4, and 96.3%, respectively. When the flocculant was introduced, we observed separation of free water from the sediment and increase of filtrate transparency compared to the natural sediment. However, at PAA dose 0.5% m/m the filtrate viscosity significantly increased, which indicated high PAA concentration in it. For subsequent investigations we have accepted the PAA dose equalling 0.3% m/m.

Poorly compressible finely-dispersed materials are recommended as fillers; they do not change the charge of sediment particles and generate the macroporous structure, which increases the water yielding capacity [9, 16, 18–21]. The examples of fillers are powdered activated carbon, diatomaceous or wood powder, pearlite, vermiculite, electrofilter dust. For the investigations we have used vermiculite, widely used material from the hydromica group. As can be seen from Table 3, the elemental composition of vermiculite, determined by us, is close to the natural water sediment composition.

Table 3. Elemental composition of vermiculite.

Element	C	O	Al	Si	Fe	Ca	Mn	S, P	Mg	K, Na	Ti
% m/m	18.02	58.24	3.58	6.03	6.95	0.81	0.16	0.14	2.52	2.56	1.00

In order to study the influence of vermiculite on the sediment water yielding capacity, we added a sample of vermiculite to 100 mL of the sediment; after mixing a dose of the flocculant was introduced (freshly prepared 0.1% PAA solution). The doses of vermiculite equalled 0.6, 1.2, 2.0, and 3.5% m/m, in conversion to dry solids of the precipitate.

Table 4. Grain-size composition of the conditioned sediment, % m/m

	Particle size, μm			
	Coarse-grained suspensions more than 300	Fine-grained suspensions 250…100	Slurry-like particles 90…11	Sludge-like particles 10…0.8
Frozen sediment	1.5	42.0	47.5	9.0
PAA 0.3 %	13	35.0	35.0	17.0
PAA 0.3 % and vermiculite 0.6 %	25.5	33.5	29.0	12.0
PAA 0.3 % and vermiculite 2.0 %	3.5	37.0	44.5	15.0

Analyzing the grain-size composition data of the conditioned sediment (the figure and Table 4), we note that in the frozen sediment the amount of coarse-grained particles decreased to 1.5%, at that the particles larger than 400 μm are absent. Freezing narrows the size distribution diagram: the fine-grained and slurry-like particles together amount to 89.5%; the fraction of the particles with the size less than 10 μm decreases by 1.6 times. Obviously, freezing the sediment causes breaking the loose coagulated structures, forming the gel-like sediment in settling basins. This process is accompanied by isolation of intermicelle water into a separate phase. After subsequent thawing this water is mainly contained in intermicellar space, the suspension is not restored to the initial gel structure, it forms the sedimentary unstable sol. In fact, when the sediment thaws, the suspension splits into the supernatant fluid and the residual solids, at that the caked suspension parts are more closely packed, for reasons of their smaller sizes. In several experiments concerning determination of the specific filtration resistance we observed the formation on the filter surface of the caked layer, which impeded subsequent filtration.

Size distribution of the sediment particles, treated by PAA and 2% (m/m) vermiculite, is similar to the frozen sediment: the fraction of the particles with the size greater than 420 μm is absent, there are 3.5% of coarse-grained particles and 81.5% of fine-grained and slurry-like particles. Evidently, such ratio of PAA and the filler enables the water, included into the gel-like structure, to be partially redistributed between the sediment and the introduced flocculant. At the same time the filler interferes with close packing of the sediment particles on the filtration membrane, it forms the macroporous structure, which increases the water yielding capacity of the sediment. The results of the size distribution analysis are correlated to the data of Table 4: after the freezing effect it is exactly after introducing 2% (m/m) vermiculite, in conversion to dry solids of the precipitate, that the lowest values of the moisture content and the specific filtration resistance – 92.6% and 625×10^{10} m/kg – are obtained.

Conditioning with PAA only, to the amount of 0.3 % m/m, is not enough for significant redistribution of the water, included into the gel-like structure: the size distribution of this sample is the nearest to the natural sediment (as the figure shows), the values of the specific filtration resistance and the moisture content of the cake are maximal compared to other methods of sediment conditioning (Table 5). Introduction of vermiculite to the amount of 3.5% does not lead to the subsequent increase of the water yielding capacity of the precipitate. Probably, it is the presence of a flocculant that causes redistribution of water between the water, included into the gel-like structure, and the free water, then at its specified concentration the introduction of vermiculite in excess of the optimal dose is unpractical.

Table 5. Principal characteristics of sediments

Treatment conditions	Cake moisture content, %	Specific filtration resistance, $r\times10^{10}$, m/kg
Natural sediment	97.0…97.2	6300
Frozen sediment	75.3	146
PAA 0.3 %	95.4	1861
PAA 0.3 % and vermiculite 0.6 %	94.5	1394
PAA 0.3 % and vermiculite 1.2 %	93.3	379
PAA 0.3 % and vermiculite 2.0 %	92.6	405
PAA 0.3 % and vermiculite 3.5 %	92.5	625

To summarize, on the basis of the study the elemental composition of the sediment in the water-supply network treatment facilities has been determined, its grain-size composition and the specific filtration resistance have been ascertained, as well as the cake moisture content for the natural and conditioned sediments. The analysis of the obtained experimental data allows recommending the "freezing – thawing" method or the simultaneous treatment of the sediment by vermiculite and the PAA-based flocculant in order to intensify the dehydration process. For the investigated sediment is has been ascertained that the optimal ratio of reagents is 0.3% m/m PAA and 0.2% m/m vermiculite, which helps to decrease the specific filtration resistance to amounts that are acceptable for mechanical dehydration of sediments with pressure filters.

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